1

REPORT OF SURVEY CONDUCTED AT

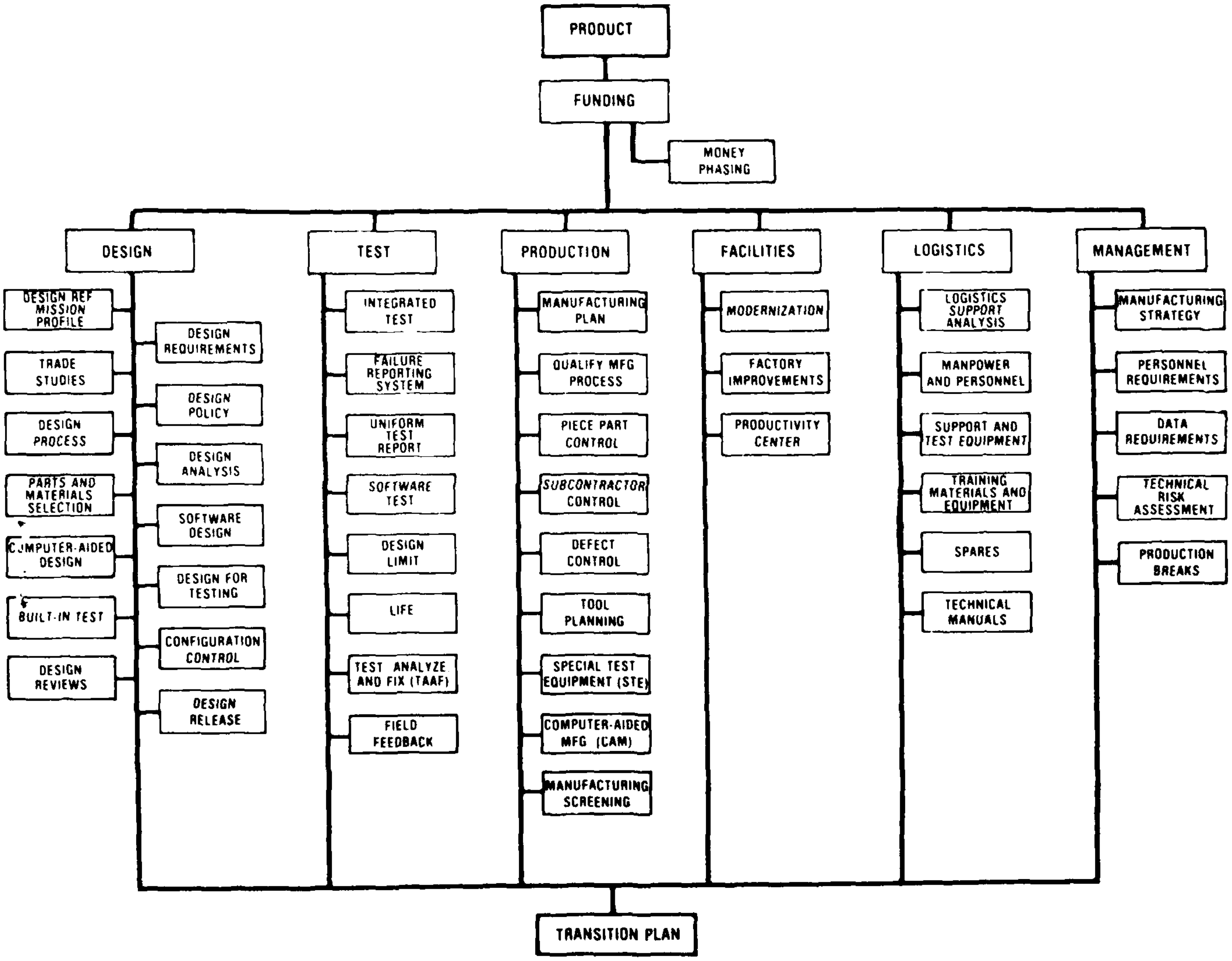
TEXAS INSTRUMENTS
DEFENSE SYSTEMS AND
ELECTRONICS GROUP

DALLAS, TEXAS

JUNE 1988

DoD 4245.7-M, "TRANSITION FROM DEVELOPMENT TO PRODUCTION"

CRITICAL PATH TEMPLATES



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 88

3. REPORT TYPE AND DATES COVERED
BMP Report June 88

4. TITLE AND SUBTITLE
Best Manufacturing Practices Survey Conducted at
Texas Instruments Defense Systems and Electronics Group
Dallas, TX

5. FUNDING NUMBERS

6. AUTHOR(S)
Office of the Assistant Secretary of the Navy (RDA)
Best Manufacturing Practices Program

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Office of the Assistant Secretary of the Navy
(Research, Development & Acquisition)
Product Integrity Directorate
Washington, D.C. 20360-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same as Number 7.

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
~~No Foreign Distribution~~

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of the Best Manufacturing Practices (BMP) survey conducted at this facility was to identify their best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout the U.S. industrial base. The actual exchange of detailed data will be between contractors at their discretion. A company point of contact is listed in the report

The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry.

14. SUBJECT TERMS

15. NUMBER OF PAGES
35

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

CONTENTS

CONTENTS (Continued)

FIGURES

SECTION 1

EXECUTIVE SUMMARY

The Best Manufacturing Practices (BMP) team conducted a survey of Texas Instruments (TI) Defense Systems and Electronics Group (DSEG). The purpose of the survey was to review and document the best practices and potential industry-wide problems at TI. The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry. The team surveyed the TI facilities in Dallas (Lemmon Avenue), Carrollton (Trinity Mills), and Sherman, Texas. These facilities produce a large number of mechanical parts for several different weapons systems.

1.1 KEY FINDINGS

There were many best practices observed at TI and detailed in this report. Some of the more significant findings included in this report are summarized below:

SECTION 2

INTRODUCTION

2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) review conducted at Texas Instruments (TI), Defense Systems and Electronics Group (DSEG) is to identify best practices, review manufacturing problems, and document the results. The intent of these reviews is to extend the use of progressive management techniques as well as high technology equipment and processes throughout industry. The ultimate goal of the BMP program is to reduce the life cycle cost of defense systems and strengthen the U.S. industrial base by using these techniques and technologies to solve manufacturing problems and improve quality and reliability.

To accomplish this goal, a team of Navy engineers supported by representatives of the NIST (NBS) and the Department of Energy accepted an invitation from TI to review and document the most advanced manufacturing processes and techniques used in their facilities located in Dallas (Lemmon Avenue), Carrollton (Trinity Mills), and Sherman, Texas. The review was conducted on 21-24 June 1988 by the team identified in Appendix B of this report. TI is engaged in the production of several different weapons systems at these locations.

The results of BMP reviews are being entered into a database to track the best practices available in industry as well as common manufacturing problems identified by industry. The information gathered is available for dissemination through an easily accessible central computer. The actual exchange of detailed technical data will take place between contractors at their discretion on a strictly voluntary basis.

The results of this review should not be used to rate TI among other defense contractors. A contractor's willingness to participate in the BMP program and the results of a survey have no bearing on one contractor's performance over another's. The documentation in this report and other BMP reports is not intended to be all inclusive of a contractor's best practices or problems. Only selected non-proprietary practices are reviewed and documented by the BMP survey team.

2.2 REVIEW PROCESS

This review was performed under the general survey guidelines established by the Department of the Navy. The review concentrated on the functional areas of design, production, facilities, and management. The team evaluated TI's policies, practices, and strategies in these areas. Furthermore, individual practices reviewed were categorized as they relate to the critical path templates of DOD 4245.7-M, "Transition From Development To Production." TI identified potential best practices and potential industry wide problems. These practices and problems and other areas of interest identified were discussed, reviewed, and documented for dissemination throughout the U.S. industrial base.

The format for this survey consisted of formal briefings and discussions on best practices and problems. Time was spent on the factory floor reviewing practices, processes, and equipment. In-depth discussions were conducted to better understand and document the practices and problems identified.

2.3 NAVY CENTERS OF EXCELLENCE

Demonstrated industry wide problems indentified during the Best Manufacturing Practices surveys may be referred to one of the Navy's Centers of Excellence. They are:

* Automated Manufacturing Research Facility (AMRF)
  Gaithersburg, MD

* Electronics Manufacturing Productivity Facility (EMPF)
  China Lake, CA

* Metalworking Technology Incorporated (MTI)
  Johnstown, PA

2.4 TEXAS INSTRUMENTS OVERVIEW

The TI Lemmon Avenue facility is located in Dallas, Texas and is dedicated to producing fabricated piece parts for the Defense Systems and Electronics Group. A site population of 1200 produces 3.5 million parts each year from an active part base of 16,500. The Lemmon Avenue facility supports an average of 150 different defense programs involving radars, avionics, electro-optics, and missile systems. Lemmon Avenue has full metal fabrication capabilities including a recently completed paint facility and an upgraded chemical processing line. Machining is accomplished with 77 numerically controlled (NC) machine tools and 142 conventional machines. Approximately 45% of the parts produced have tolerances of $\pm$ .001 inch.

The TI Sherman site occupies 750 acres of land and has 1,237,000 square feet of air conditioned floor space. This site is co-occupied by two major TI business groups, Semiconductor Operations and Defense Systems and Electronics Group, with the total site population approaching 3,900 employees. The primary DSEG product lines at this site are PAVEWAY and HARM missile components. PAVEWAY is a series of laser-guided munitions, which includes the Low-level Laser-Guided Bomb, featuring launch-and-leave capabilities. HARM (High-Speed Anti-Radiation Missile) is an air-to-ground missile used for suppression of enemy air defense systems. This facility produces 3.4 million parts per year with an active parts base of over 2,500. Forty percent of these parts fall in the high to moderate volume category with another 32% requiring precision machining. The machine tool complement includes 94 NC machines, 175 conventional machines, and 52 special machines.

The TI Trinity Mills facility is located in Carrollton, Texas. It occupies 150,000 square feet with 85,000 square feet of machining area. Employment at this site is 500 people, with approximately 330 involved in manufacturing. The machine tool complement includes 66 NC machines, 99 manual machines, and 27 special machines. These machines are divided into cells using a group technology approach. One of these cells is a four machine FMS handling 48 different operations. Major production programs are the Tank Thermal Sight, which is used on a number of tanks and provides target acquisitioning and fire-control capabilities, TOW family of portable antitank guided missile systems, Common Mod, which is used in a number of forward looking infrared systems, and HARM. Approximately 80% of the parts produced are machined from aluminum castings, 10% from steel, and another 10% from aluminum plate. These parts include over 60% requiring a tolerance of ± .001 inch.

2.5 ACKNOWLEDGEMENTS

Special thanks are due to all the people at TI whose participation made this survey possible. In particular, the BMP team acknowledges the special efforts of Mr. Allan Hrncir, Mr. John Richardson, and Mr. Michael Leake. Without their efforts, this survey would not have been possible.

2.6 TI POINT OF CONTACT

While the information included in this report is intended to be descriptive of the best processes and techniques observed at TI, it is not intended to be all inclusive. It is anticipated that the reader will need more detailed data for true technology transfer.

The reader is encouraged to contact TI directly for the purpose of sharing or transferring technology. Any exchange of technology resulting from such a contact is strictly voluntary and at the discretion of TI.

The TI point of contact for the Best Manufacturing Practices Program is:

Mr. Allan Hrncir
Engineering Manager
Texas Instruments
Defense Systems and Electronics Group
6000 Lemmon Avenue
P.O. Box 660246, M/S 542
Dallas, TX 75266
(214) 956-6469

SECTION 3

BEST PRACTICES

The practices listed in this section are those identified by the team as being among the best in the industry or as being particularly effective in TI's efforts to reduce life cycle costs of its products.

3.1 DESIGN

PRODUCIBILITY ENGINEERING

The Producibility Engineering group is an integral part of the design, manufacturing, and purchasing functions. It is comprised of very experienced engineers, who work closely with the design engineers, providing assistance and guidance and helping to resolve specific design issues. The group develops baseline part costs to aid in alternative design decisions. These are reviewed and updated as the design progresses. They are active participants in parts and materials selection. They also work closely with the model shop in the prototype phase and assist in proof of manufacturing efforts. All fabrication drawings must be approved and signed by Producibility Engineering. In the production phase, they provide continuity on major components after the design engineers have left the program.

The Producibility Engineering function is essential for a smooth transition from development to production. It is done very effectively at TI using highly experienced people in key disciplines with the authority to control the process.

PRODUCIBILITY ADVISOR

TI is developing a PC based Producibility Advisor program to assist the mechanical design engineer. It is menu driven with screens arranged by feature, attribute, and method of fabrication. General producibility guidelines that are not associated with any one feature, including cost factors for ranking different processes, are also provided. Graphic material may be displayed. Currently in the prototype stage, the system effectively automates many of the tasks associated with the design engineer's job. Because it is accessible and easy to use, it has the potential to greatly speed up the design process and reduce errors. A design rule checker feature, which will analyze the design for conformance to producibility guidelines, is also under development. Plans call for the advisor to be fully operational by 1990 and the checker by 1991. Both systems are part of TI's phased implementation of CAD/CAM.

DIMENSIONLESS DRAWINGS

TI has the ability, through the use of the Computervision CAD/CAM database, to produce dimensionless part models for prototype efforts. By using the dimensions embedded in the various NC geometric part models plus a minimum of key dimensions or critical tolerances from the design engineer, prototypes can be produced in days rather than weeks or months. Examples of some of the benefits of dimensionless drawings were presented.

Two examples discussed were a control handle and a mirror housing. In the case of the control handle, the engineer changed the design when he reviewed the dimensionless model and saw that it was not what he really wanted. In the second case, the mirror housing was produced using less than a half dozen critical tolerances. TI has completed over 200 designs to date using this technique.

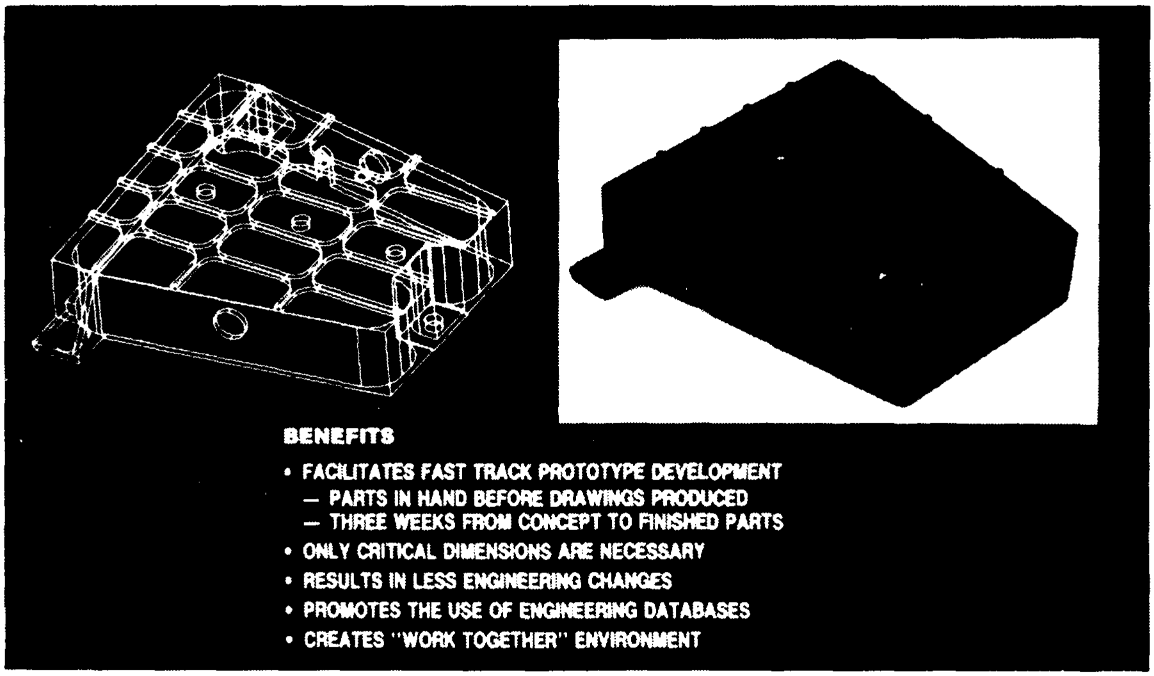


FIGURE 3-1: Dimensionless Drawings

3.2 PRODUCTION

JUST-IN-TIME

The TI Sherman site has implemented Just-in-Time (JIT) and Total Quality Control (TQC) concepts on the PAVEWAY and HARM missiles and has worked with its vendors to develop the same practices, resulting in a 90% improvement in overall fabrication and assembly quality and a 60% improvement in actual on-time deliveries. TI initially implemented JIT to provide the capability for the simultaneous production of the PAVEWAY II and III missiles without additional warehouse space. TI's approach was to develop a hybrid JIT concept that utilizes pull-through scheduling. JIT was implemented on 29 part numbers for the PAVEWAY II and, prior to its cancellation, 43 part numbers on the PAVEWAY III.

A reduction in PAVEWAY fabrication staffing from 55 to 30 people was achieved as a result of the JIT implementation. TI's JIT philosophy stresses employee involvement at all levels through effective two-way communication. This is accomplished by the use of Effectiveness Teams (which were already established), personnel training, a continuous effort towards higher standards of quality and efficiency, and reduced Work-in-Process (WIP) and cycle times.

Dedicated teams plan production by evaluating part requirements, determining a manufacturing approach, and subsequently designing the system. Parts are manufactured based on planned daily unit loads using daily schedules, small lots, and less than full capacity scheduling. Inventory is controlled through WIP and cycle time models.

JIT results for PAVEWAY have shown:

* 50% decrease in machine set-up times.
* 47% decrease in WIP levels for fabrication and assembly.
* 47% decrease in scrap parts in fabrication and assembly.
* A decrease of 50,000 square feet of warehouse and manufacturing space requirements from the original plan.

JIT is utilized on eight dedicated cells for HARM missile production. Overall HARM fabrication cycle time was reduced from 13 weeks to 2 weeks through the effective implementation of JIT.

Some of the significant results of JIT on the HARM missile fabrication efforts are:

* 87% increase in production rate.
* 86% reduction in set-up time.
* 48% reduction in WIP.
* 55% reduction in WIP investment.

TOTAL QUALITY CONTROL

Total Quality Control (TQC) at TI has been designed to control manufacturing processes at the point where the work is performed through the development of detailed inspection plans and preparation of gaging kits for each operation.

The responsibility for defect detection has been moved from the quality control organization to the manufacturing organization in order to provide immediate feedback and the opportunity to control the process. Quality control inspectors now serve as facilitators to help control the process. Cell operators are responsible for part inspection, part quality, and machine maintenance. Automated in-line inspection has been fully integrated into robot controlled cells. Final inspection utilizes coordinate measuring machines (CMM) instead of functional fixturing to obtain variable data and immediately identify out-of-tolerance features. TI uses measures such as statistical process control, defect analysis, and process improvement to avoid potential problem areas. Statistical profiles of part features are developed from CMM output data. These profiles are compared to design tolerances to identify features which may require modifications in machines, tooling, or design tolerances. Additional data is obtained once the changes are made to verify the effectiveness of the action.

Operators are cross-trained to run any machine within a major cell and are briefed to understand the customer's problems and concerns. TI also works with suppliers to help solve communication and manufacturing problems and help them develop improved quality capabilities such as automated gaging.

Vendor control is maintained by TI on-site source inspectors, who inspect parts prior to shipping. Most defective parts received by TI are returned to the vendor for corrective action in order to maintain problem awareness at the vendor's site.

TOOL MANAGEMENT

The fundamental aspect of a successful tool management system is to have the correct tool available for the operator when it is required. To accomplish this goal, TI is creating a distributed network of tooling databases that supports Methods and Tooling, Inventory Control, Purchasing, Incoming Inspection, and Tool Regrinding. The network links several manufacturing sites located throughout North Texas and Colorado providing central coordination for cutting-tool management. Previously, each site maintained its own tool database.

The standardization involves all standard stocked cutting tools, each of which has several parameters loaded into the database. Configuration management is now centrally located and maintained. When the system is completed, inventory control and production engineering applications will be distributed to the site level. This reduces redundancy and data is available at all sites. Each site has control over its local subset of tools and may stock and use certain tools unique to their needs. Tooling can be transferred among the different sites if necessary.

The system's database gives information as to fault analysis and the relative quality history of different tool suppliers. The database also allows lot purchases of high usage tools for all sites.

Three years ago, tool inventory was at the $3 million level. It has now been reduced to half that amount.

REAL TIME X-RAY INSPECTION

TI's Trinity Mills Plant is in the final stages of adopting real-time X-ray as a technique for 100% inspection of HARM missile wing spar to trailing edge welds. By incorporating this nondestructive inspection technique and other related processes in-house, Trinity Mills will improve process control and eliminate excessive product transfers. As a result, production cycle times will be reduced from eight weeks to five weeks with associated WIP reductions. The primary benefit, however, is realized from the elimination of the need to rely on lot acceptance procedures, which require only 10% inspection. Because of the real-time nature of the process, it is possible to inspect the entire lot and to utilize the results for improved process control. Real-time X-ray provides immediate feedback to the welding operation, thus preventing accumulated production of unacceptably welded parts, which otherwise would receive no inspection until one or more lots were fabricated.

Two level III ASNT certified TI personnel have received inspector training from the real-time X-ray equipment supplier. The TI system utilizes an IRT HOMX 161 real-time X-ray unit, optical disk storage for unprocessed image data, an ARD-2 System 700 image processor, an AG-6200 video cassette recorder for processed images, a high resolution color monitor, and a five-axis work piece manipulator.

PHASED IMPLEMENTATION OF CIM

TI is integrating CAD and CAM systems through a three-phase plan covering a five-year period. Advanced capabilities will be achieved by progressing from basic part drawing transfer between CAD systems to developing the advanced technology, methodologies, and organizational structure to support totally integrated generation of product data.

CAD/CAM utilization is already extensive throughout the Division. Full implementation, including distributed data management, is planned by 1991 to achieve a fully "paperless" factory for all phases of design and manufacturing. The goal is to produce high quality part design and manufacturing data that, due to thorough analysis of all needs, will require few if any changes after part production, assembly, and testing has begun.

The integration approach will use a common approved design database and a methodology that is based on iterative analysis of engineering design data. TI anticipates that a part design that has been through a thorough quality, reliability, producibility, and maintainability analysis will require few engineering change notices after the design phase and will provide better information to the manufacturing, assembly, and system testing functions.

INTEGRATED NUMERICALLY CONTROLLED PROCESSING AND CONTROL SYSTEM/TERMINAL FOR REMOTE INTERFACE AND CONTROL SYSTEM

The Integrated Numerically Controlled Processing and Control System (INPACS) provides TI with a distributed manufacturing capability for NC machines, which has completely eliminated paper tape. The system is installed at six locations and is connected to 260 CNC machines with over 70 different types of CNC controls. It is composed of a main computer at each site linked to microprocessor based terminals at each numerically controlled machine. For each NC job, INPACS is used to generate the Automatically Programmed Tool (APT) source program, provide operator instructions and set-up requirements, create the tooling list, and track job revisions.

A major component of the system is the NC terminal at each machine, which is called the Terminal for Remote Interface and Control System (TRICS). Each TRICS unit is connected to the site computer and controls the NC machine using instructions stored internally on a 20 megabyte hard disk drive. The terminal contains the NC data needed by the NC operator to run the part. Since each terminal has a substantial memory capacity, maintenance downtime can be scheduled on the main site computer without disrupting shop operations. Another special function of TRICS is real-time Statistical Process Control (SPC) at the NC machine, which allows the operator to monitor and control the process and reduce in-process inspection requirements.

INPACS/TRICS has been operational at TI since 1984. The system has been very successful in increasing NC productivity, reducing machine idle time, and reducing software and processing costs.

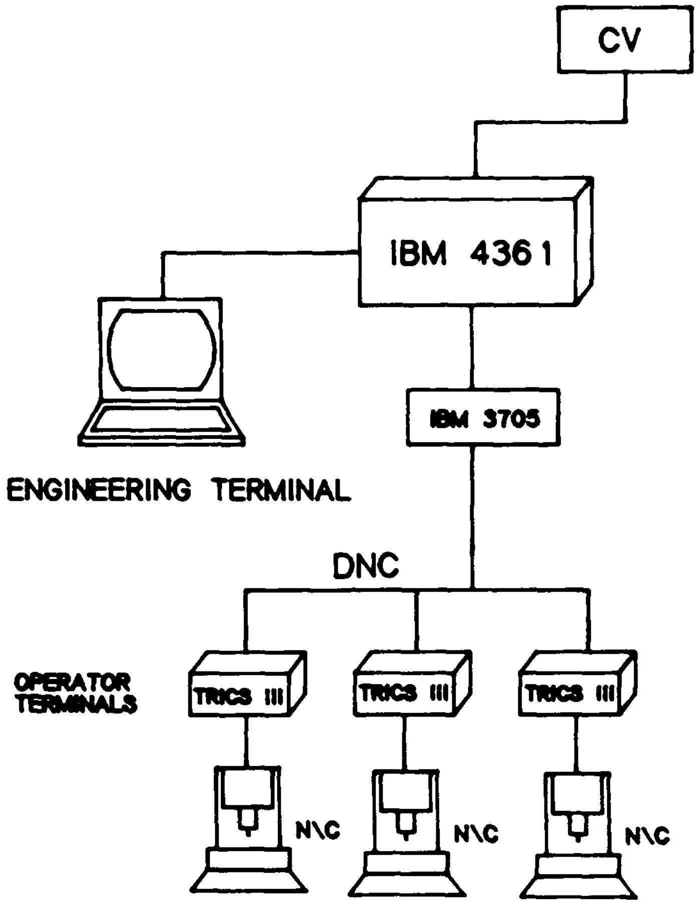


FIGURE 3-2: INPACS Architecture

AUTOMATED PROCESS PLANNING RESEARCH AT NIST

TI has been active in improving its process planning capability. They have progressed from manual planning to an interactive system and are currently planning for the future use of artificial intelligence to control much of the planning. A coordinated research and development program has been instituted toward that end.

The program is focused on a semi-automated process planner and an NC programming system based on artificial intelligence and mechanical design technologies. For the past three years, the artificial intelligence portion of the program has been worked in conjunction with the Navy sponsored Automated Manufacturing Research Facility (AMRF) at the National Institute of Standards and Technology to develop problem solving strategies. The logic involved is based upon the loose coupling of equipment to processes, thus reducing combinatorial explosion.

To date, the effort at the AMRF has resulted in the delivery of a feature planner prototype running on a TI Explorer system. The proof-of-concept prototype is made up of an expert system feature planner and a metal fabrication knowledge database. The planner, called a Semi-intelligent Process Selector, works at the individual part features level to accomplish operation level planning functions. It selects the process and sequencing based upon costs and time to complete each feature.

The semi-intelligent process selector utilizes mouse driven screen icons and information windows. The information portion of the program is made up of a series of branches with each node representing information about the relationship of features, relative cost, and any restrictions or required actions. The system considers the primary process involved plus any needed feature improvement process and conjunctive feature. Although the AI program can select the optimum tool and feature plans, the operator may ask for options. The tool selection includes the cutting tool, holder, adapter, as well as the feeds and speeds.

Near-term plans are to expand the system to address additional feature types. Future plans are to install all of the information on a Sun/Computervision system and utilize electronic production definition data to directly drive the planning function.

USER SUPPORT UTILITIES FOR NC PROGRAMMING

TI has developed two software packages that aid NC programmers in selecting cutting tool components and specifying machining parameters. The machining expertise incorporated into the packages allows a relatively inexperienced programmer to generate reliable data.

The Holder/Adapter Selection System (HASS) automatically selects the components of an optimum cutting tool assembly. HASS uses data supplied by the NC programmer, such as cutting parameters, interference clearances, and rigidity requirements, and the specific cutting tool to be used. The NC programmer does not have to do calculations or search through component catalogs. The expert system automatically selects the optimum holder, collet, and adapter components required.

The Speeds and Feeds (SAF) module calculates machining speeds and feeds for drilling and end milling that achieve required part quality while optimizing production. Material and cutter characteristics are described in a SAF database. The NC programmer inputs information describing tool and part rigidity and cutting parameters. SAF automatically generates reliable speed and feed rates. The system also assists new programmers in learning correct machining practices.

3.3 FACILITIES

POWDER PAINT APPLICATION

TI has recognized the inherent disadvantages associated with the application of conventional solvent based paint systems. In order to eliminate shortcomings in the areas of personnel safety, environmental impact and process quality, a program has been started at the Sherman site to qualify powder painting as an alternative manufacturing process. Stainless steel HARM missile fins, wings, actuators, seeker sections and control sections have been selected for part by part process qualification prior to rate production and adoption of the process by other product lines.

The process utilizes Glidden thermoset epoxy powder applied electrostatically in a spray booth supplied by Reclaim Corporation. The booth operates in a temperature and humidity controlled area and features two operator platforms, a self-contained powder recycling system and an ultraviolet detection system. Following paint application, parts are transferred via overhead conveyor to a convection curing oven operating at 300° F to 400° F. Curing is critical and is monitored on a part-by-part basis using thermal contacts, thermal barrier, temperature recorder, keyboard and printer, all supplied by Data Pak.

To develop certified factory operators, representative test panels accompany the part being painted through the spray booth. However, prior to curing the painted part, the cured test panels are laboratory analyzed to confirm adequate adhesion hardness and thickness. This allows the uncured painted part to be easily stripped by the use of compressed air and repainted as many times as necessary to produce an acceptable finish. Operator training is also being conducted utilizing videotaping techniques and statistical quality control.

The major benefit realized from the powder paint application process is the elimination of the solvent transfer medium, which is the source of hazardous volatile organic compounds emitted during mixing and curing.

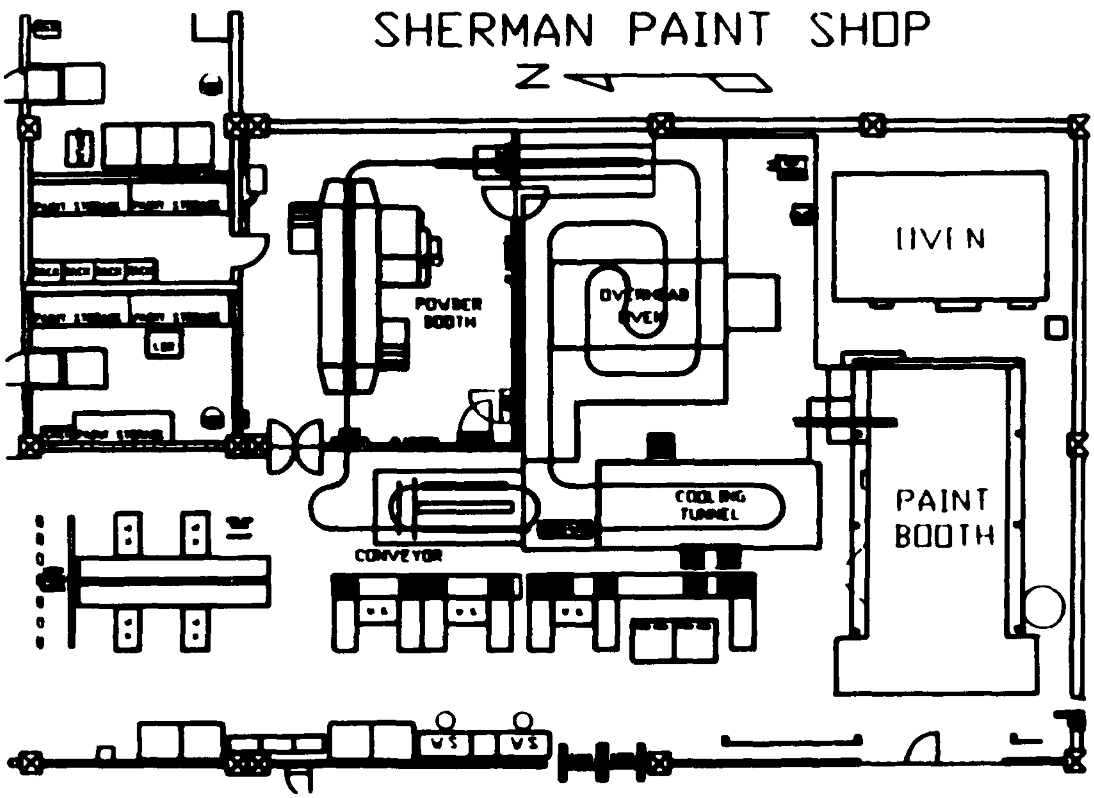


FIGURE 3-3: Powder Paint System

FLEXIBLE MANUFACTURING SYSTEM (TRINITY MILLS)

TI has developed, installed, and is currently using a flexible manufacturing system (FMS) to machine 39 different prismatic aluminum castings or billets on a three shift basis at Trinity Mills. The system consists of the following:

* Four CNC Niigata horizontal machining centers, each with a 90 tool magazine.
* Two GMF deburr robots, each with a positioning table that will hold two pallets.
* One Sheffield Apollo coordinate measuring machine.
* A dual position wash station using a water soluble solvent.
* A ten pallet carousel used to load and unload work for the cell.
* One wire guided vehicle which moves one pallet at a time to the various work stations.

The controls for the system combine mature TI developed manufacturing floor control systems and NC program support with artificial intelligence for planning, scheduling, and dispatching. These controls determine machining schedules based on production goals and resource capabilities. They supervise the cell controller, track cutting tools, schedule replacements, and provide instructions and data to other systems in real-time.

The Trinity Mills FMS is a self-contained manufacturing cell for machining, deburring, washing, and inspecting piece parts automatically. Though not currently planned, the system has the capability to operate unattended for prolonged periods of time. Since becoming operational in 1987, the FMS has satisfied or exceeded all expectations. Machine utilization has doubled, manufacturing costs have dropped significantly, and quality has improved and is now more consistent and predictable.

FIGURE 3-4: FMS at Trinity Mills Plant

FLEXIBLE MANUFACTURING SYSTEM (LEMMON AVENUE)

TI installed a Fritz Werner flexible manufacturing system at the Lemmon Avenue Plant in October 1986. A two machine system was originally installed and has been upgraded to four machines. Each center has a full 4-axis capability, 20 inch working envelope, 60 tool magazine capacity, and a 6 sigma accuracy of 0.0006 inch. In addition, the system has an automatic pallet transport system with 16 pallet buffer storage, a robotic tool supply system, and an integrated tool presetter. It is controlled by a Gildemeister 4 megabyte system.

The robots and computer controlled system allow for unmanned NC machine operation. Machine utilization has increased from 30% to over 60%. The system software schedules parts, automatically replaces worn tools, monitors machine or tool malfunctions, controls robotic tool loading, tracks all tool inventories and part pallets, and controls cutting operations. When these systems are fully implemented, TI expects to increase machine utilization to 80%, realize a 2.5 to 1 productivity gain, and eliminate all problems associated with storing and handling of fixtures.

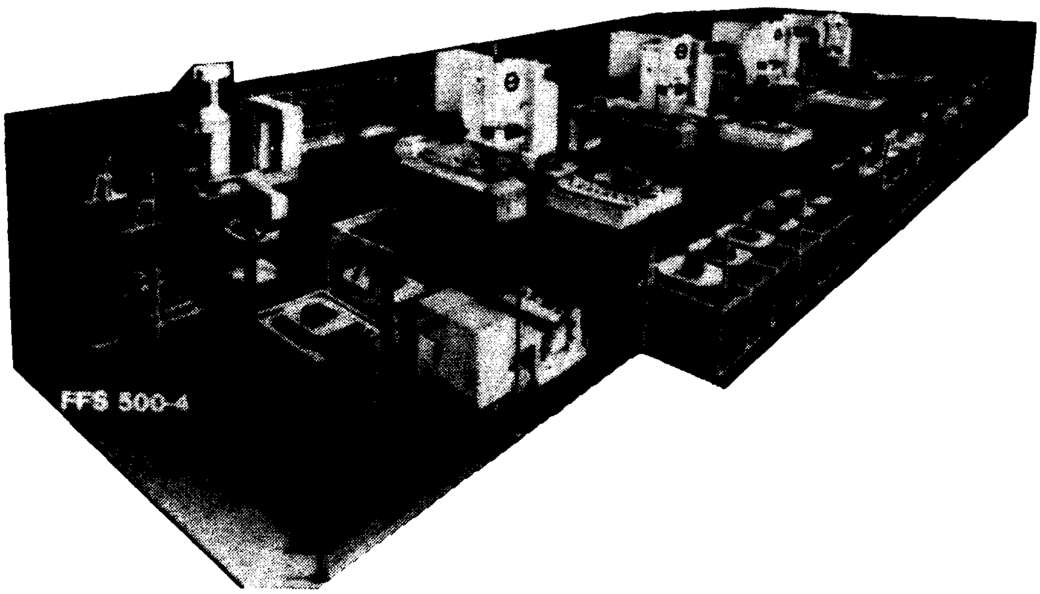


FIGURE 3-5: FMS at Lemmon Avenue Facility

FLEXIBLE MANUFACTURING CELLS (SHERMAN)

The TI facility in Sherman has developed and implemented several flexible manufacturing cells to produce a wide variety of machined parts. One of the most effective of these is the screw machine cell. This cell consists of 16 CNC screw machines. There are also 14 cam driven manual machines and several other pieces of support equipment. The screw machine cell is capable of producing turned parts with finished tolerance requirements ranging from $\pm$ .001 to $\pm$ .010 inch. The cell operates on a three shift basis and provides just-in-time capability on selected HARM missile parts.

Operators are responsible for the total quality of all work performed within the cell. This includes programming the CNC machine controller, setting-up and operating the machines necessary to produce the parts, and deburring and inspecting the finished part prior to shipping. Ownership at all levels for the work performed in this cell has been achieved by getting everyone involved in the process and giving them the responsibility and authority to initiate changes that improve the finished product. When a part leaves the cell, all machine work is complete.

ROBOTIC DEBURRING CELL

TI implemented a robotic deburring cell at the Trinity Mills Plant using a GMF S-110R robot and a Karel controller. The cell eliminates most of the manual deburring required on two different machined aluminum castings. Part programming is done off-line and downloaded to the cell controller. However, robot orientation must first be established through the use of a teach pendant.

Parts to be deburred are manually loaded onto a gravity feed queue rack and part identification is loaded into the cell controller. The parts are robotically loaded onto a simple generic tooling fixture designed to accommodate both parts. The fixture is mounted on a rotary table to allow deburring of the entire part with minimum robot arm extension and wrist rotation. End-effectors for deburring holes, edges and bosses are stored on a storage rack capable of holding 24 end-effectors. End-effectors are driven by air motors and have built in compliance locators to allow for X, Y, and Z axis variations.

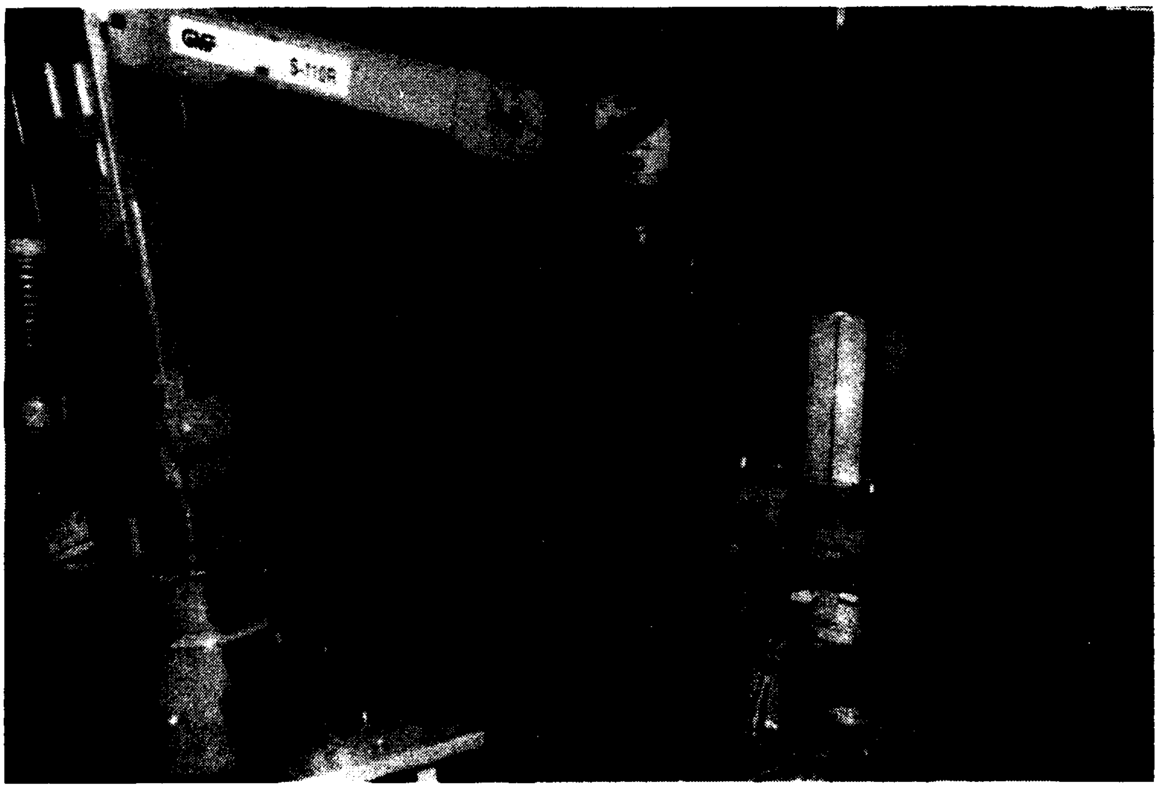


FIGURE 3-6: Robotic Deburring Cell

WATER JET CUTTING SYSTEM

TI has implemented a water jet cutting cell at the Sherman Plant to replace manual cutting techniques, which use knives, metal templates and dies to cut dielectric foam materials and rubber.

Cutting patterns are developed off-line on a CAD system and downloaded to the cell controller. A Flow Systems high pressure pumping unit and a GAMATA water jet head produce up to a 60,000 psi stream with an adjustable diameter from .004 inch to .030 inch. The cutting bed is a large X-Y table with the water jet mounted in the Z-direction. The cell incorporates a dual cutting bed system to allow for part removal and set-up without machine down-time. The beds shuttle above and beneath each other for manual loading or unloading from the same position.

Water jet cutting has reduced cycle time from six minutes to roughly 30 seconds with excellent edge quality. New part tool-up can be accomplished in a matter of hours.

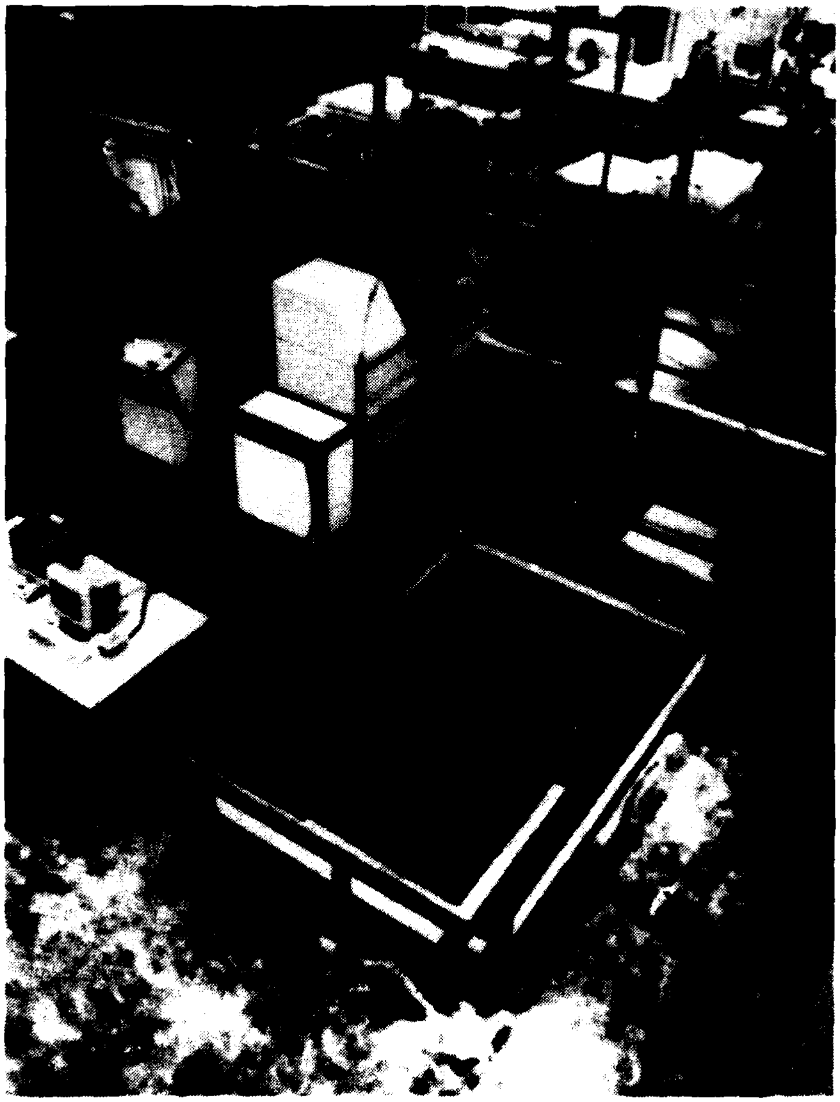


FIGURE 3-7: Water Jet Cutting System

LASER CUTTING SYSTEM

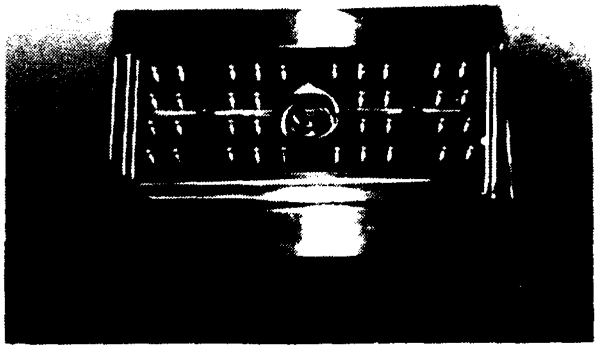
TI adapted a Laserdyne laser cutting system to fabricate .020 to .050 inch aluminum thermal planes at Lemmon Avenue. These planes were previously cut by a chemical etching process, which had a number of disadvantages, including chemical waste, inconsistent quality, slow production rates, and relatively high cost. The Laserdyne system has a cutting velocity of up to 600 ipm using an 1800 watt peak power Coherent EFA-51 laser with an eddy current height sensor. The process has excellent repeatability, is comparatively inexpensive, and requires no unique hard tooling. Using this process, TI has achieved a 4 to 1 productivity improvement over the etch process. The current system produces over 40 thousand parts per year.

FIGURE 3-8: Laser Cutting System

MACHINE TOOL ACCEPTANCE TEST

TI, Trinity Mills has developed a machine acceptance test part that is now being used by all of the manufacturing sites. This test part measures the machine accuracy and repeatability performance under actual cutting conditions. Unlike the current ANSI standard test part, (Circle, Diamond, Square), this test part is able to provide a statistically significant data sample from one test piece. It evaluates the machine capabilities, not the process. It is much quicker to produce, taking only two hours to machine and inspect as opposed to 51 hours using the current ANSI test part to gather similar data. This reduction in elapsed time eliminates time dependent variables such as different operators or inspectors as well as changing temperatures during the day and night. This test part provides data for current machine conditions. It also establishes a base line and point of reference for historical performance. Machines can be evaluated and measured for any changes during their life cycle. TI has presented this test part to the ASME/ANSI B5 committee for evaluation as a possible ANSI standard test for machine tools.

CIRCLE / DIAMOND / SQUARE
DISADVANTAGES:
- FIFTY-ONE HOURS TO MACHINE AND INSPECT 30 TEST PARTS.
  - 36 HOURS MACHINE TIME
  - 15 HOURS INSPECTION TIME
- PROCESS IS EVALUATED, NOT MACHINE CAPABILITIES.
- INTRODUCES MANY VARIABLES
  - MORE THAN ONE OPERATOR
  - MORE THAN ONE INSPECTOR
  - TEMPERATURE VARIANCE



STATISTICAL TEST PART
ADVANTAGES:
- TWO HOURS TO MACHINE AND INSPECT 1 TEST PART.
  - 1 HOUR MACHINE TIME
  - 1 HOUR INSPECTION TIME
- MACHINE CAPABILITIES ARE BEING EVALUATED AND NOT PROCESS.
- REDUCES VARIABLES
  - ONE OPERATOR
  - ONE INSPECTOR
  - TEMPERATURE CONTROL

FIGURE 3-9: TI Machine Tool Acceptance Test Part is Compared to ANSI Standard Test

ROBOTICS/AUTOMATION LABORATORY

TI makes extensive use of in-house robotics/automation laboratories. This concept of prototyping and debugging systems in the laboratory prior to implementation on the production floor has proven to be an effective methodology at the Sherman plant. Most of the PAVEWAY III automation concepts were proven in this lab. The lab is currently developing an automated system for small clinch nut insertion in several different sheet metal trays on which PC boards will eventually be mounted.

An interesting part of TI's approach to the laboratory is the fact that it buys state-of-the-art equipment for the laboratory with the intent of turning the equipment over to the manufacturing organization after the laboratory has analyzed and evaluated the equipment. TI then buys additional new equipment for the laboratory. This has the beneficial effect of turning over equipment to manufacturing that has already been proven and debugged while insuring a constant supply of modern equipment for the laboratory.

ELECTRONIC LIAISON SYSTEM

The Electronic Liaison System is a real-time, PC based network which provides support to all fabrication areas within the plant to correct and eliminate problems with tooling, NC tapes, and work methods as they occur. It is a Local Area Network (LAN) utilizing Etherseries hardware and software and TI PCs connected by LAN coaxial cable. Currently, 15 PCs are used to achieve total site coverage at Lemmon Avenue. The system replaced a manual system, which was slow, inaccurate, and required excessive legwork. With the electronic system, users have real-time reporting of problems and their resolutions.

Currently, the system is handling 40 to 50 liaisons a day with an average of three problems per liaison. Most problems are resolved immediately with the assistance of Methods and Tooling personnel. Some problems require a few days to correct. In addition to providing more timely resolution of manufacturing problems, the system provides management with historical data, trend recognition, key indices, and the ability to follow-up on all reported problems.

3.4 MANAGEMENT

TRAINING OF DESIGN ENGINEERS IN MANUFACTURING PROCESSES

TI has implemented an engineering training and development program called the "Design for Manufacture Series" for young mechanical design engineering graduates starting out in the company. The objective is to improve their ability to design producible parts. TI has found that most engineering graduates receive insufficient training in this area while in school. The program uses a synergistic approach that integrates producibility, design, manufacturing, and quality disciplines. It has been very successful in improving design for producibility skills resulting in designs requiring fewer engineering changes and improved product reliability. The program covers the following subjects:

ME Training Program Orientation
Geometric Dimensioning and Tolerancing
Analysis Methodology Overview
Thermal Analysis
Design for Assembly
Machine Parts Design
Casting and Near Net Shapes
Sheet Metal Design
Nonmetallic Parts Design
Metal Joining and Finishing
AUTOCAD
MICROCAD

METHOD IMPROVEMENT REPORT PROGRAM

TI has successfully accomplished the task of implementing a "Methods Improvement" identification program. The intent of the program is to encourage employees to submit their ideas and suggestions for productivity improvements. These suggestions are documented on a one page form called a Method Improvement Report (MIR). The program encourages employees to suggest and identify improved methods of performing a task resulting in quality improvements, cost savings, cost avoidance, or safety improvements. The form is basically self explanatory and, if questions or problems occur in its completion, the employee submitting the MIR can get help from either his supervisor or the MIR Program Office. MIR forms provide a written record for the employee and supervisor as well as the input for computer files for corporate level documentation.

The success of this program is evident from the statistics for 1987. The program generated over 3900 MIRs with a participation level of 88% of the 1350 employee base. This represents approximately 3 MIRs annually per employee.

Providing a means for all employees to become involved with their job both in the planning and problem-solving areas seems to be responsible for some of the program's success. Publicity given to the program is equally responsible for the success. Employees are recognized for multiple submissions each month and total yearly submissions. Simple report requirments and assistance given to the employee in completing the form are also key factors contributing to the success and wide acceptance of the MIR program.

SECTION 4

PROBLEM AREAS

The problems described in this section were presented by TI to stimulate government and industry efforts to help resolve these problems.

LACK OF PRODUCIBILITY ENGINEERING ANALYSIS ON CLASSIFIED PROGRAMS

Producibility engineering analysis is not always included in programs from the very beginning. This is most evident in classified programs where knowledge of the program must be restricted to very few personnel. Best practice is to have producibility engineers involved in every program from the start. But sometimes, because of the need to reduce the number of people involved in these programs, producibility engineering people tend to be overlooked. There is a need to ensure that Producibility Engineering is represented on the development team of all programs, whether they are classified or not.

TI has sometimes identified this oversight only when parts are processed through the model shop that have obviously not been reviewed by producibility engineers. The model shop notifies Producibility Engineering of the faulty parts. However, at that stage, valuable time and resources may have already been wasted. There is also a hidden danger that parts with faulty designs are not identified at all, resulting in a negative impact on product reliability and maintainability. Without the proper analysis in the early stages of design, such problems would not surface until the system is fielded several years later.

NEED FOR OFF-LINE PROGRAMMING OF COORDINATE MEASURING MACHINES

Most CMM programming is currently done by teach programming the machine using an actual part. This procedure is time consuming. It makes the CMM unavailable for inspection of production parts while it is being programmed for new parts. In addition, programming cannot be performed until a good part is produced. Often, parts are made faster then they can be inspected and production equipment stands idle while waiting for first part inspection to be completed. This inefficiency is especially significant since the programming of other production equipment uses modern CAD/CAM techniques including integrated engineering databases and computer-graphics techniques.

Many CMM users are in a high volume production mode, typically automotive manufacturing. The disadvantage of teach programming is not as much of a limitation when many parts are inspected, as it is in small batch production. Most high volume CMM users are therefore not requesting off-line CAD/CAM or graphic programming capability. As a result, CMM vendors are not responding to the needs of manufacturers like TI and others in the defense manufacturing industry.

TI would like to see this problem resolved by the development of a good standard off-line programming language and neutral interchange file format that is well supported by the CMM industry. The language should also support optical and laser inspection machines.

UNAVAILABILITY OF CONSISTENT NC CUTTING TOOLS

TI commented that there is a lack of consistent quality in domestically manufactured expendable cutting tools produced for use in CNC machine tools. Standards published by such organizations as the Metal Cutting Tool Institute (MCTI) do not offer specifications, such as critical geometric tolerances, which address the CNC user.

TI has recognized that U.S. tooling manufacturers can not offer cutting tools lot-to-lot and order-to-order which meet their internal specifications with consistent geometric repeatability. Critical problems encountered when purchasing from U.S. cutting tool suppliers are such items as helix angle, flute-to-flute positioning, surface finish of the primary cutting angles, shank concentricity, axial and radial run-out, etc. Thus, TI elected to purchase a CNC grinder to fabricate end mills from qualified high speed steel or carbide blanks. Also, TI has the expertise to resharpen a manufacturer's end mill as long as it meets TI's specification.

TI feels the success of its program results from focusing on the problems which affect their overall quality production environment. Particular attention is paid to shanks and grinding details which have a direct effect on the machining process. TI has provided the major U.S. cutting tool manufacturers the opportunity to quote to its end mill specifications, but, to date, none has been able to meet the requirements.

COMPUTERIZED STATISTICAL QUALITY CONTROL

A pilot program for computerized Statistical Quality Control (SQC) has been developed and implemented at the TI Trinity Mills facility. This program grew out of the TI corporate interest in quality programs. The Trinity Mills machinists have been receiving training in statistical methods such as data collection, histograms, and time series analysis since 1984. In 1985, a prototype computerized SQC system was developed on a TI personal computer. This system was designed to interface with the Terminal Remote Interface Control System (TRICS) units that exist at each operator's station for downloading of NC programs. The objectives of the system are to develop and install a real-time SQC system utilizing existing TRICS hardware, which would provide machine operators with a tool to control their quality and to alter the QC function from part inspection to process audit. The system was installed in 1987. Benefits are expected to be realized from changes such as on-line quality history, on-line visibility of process trends, reduced rates of inspection, early exposure of process problems, and reduced defects and scrap rates.

CHEM-FINISH DATA COLLECTION, STORAGE, AND DISPLAY SYSTEM

TI's Sherman facility has developed a system to collect, store, and graphically display statistical process control data from the chemical finish shop in order to realize a more efficient and productive chemical finishing operation. Process parameters such as temperature, conductivity, and acidity are monitored at one minute intervals for numerous tanks on the passivation, Alodine, and anodize lines. This process data is then formatted by a software model for electronic storage and display. The processed data is available immediately to the operator in three basic formats:

* Overall view of all three process lines with a color classification for each tank's condition (green/good, yellow/out-of-control, red/out-of-spec);

* Individual representation of each line with current conditions and specification limits;

* Graphical display of each specific process parameter.

Action or control limits are established for each parameter to guide the operator in evaluating the process. Should any parameter for any tank fall outside the acceptable range during processing, the discrepancy is immediately identified by the color classification system on the operator's terminal along with an audible/visual signal from the control panel. Each monitored process parameter may also be displayed and plotted relative to process time. This information is then used by process engineers to reduce variation within the process.

The real-time nature of process parameter modeling also allows the operator to modify controls in advance or in anticipation of a process going out of control. The system has decreased variation within the process, which yields a more uniform product of a higher quality.

FIGURE 4-1: Chem-Finish Line

OVERDETAILING AND MISAPPLICATION OF MIL-SPECS AND MIL-STDS

TI reviewed several examples of overly restrictive MIL-SPEC and MIL-STD requirements imposed by their contracts. These specifications and standards delay the use of new and emerging technologies, are too detailed, and contain too much "how-to" information. On occasion, they specify processes and methods that are unacceptable because of environmental, safety, or statute requirements.

TI has experienced significant delays in getting revisions, deviations, and waivers to these requirements. These delays result in excessive costs, negatively impact on production and delivery schedules, and in some cases, result in an inferior product due to a limitation on the use of new technologies.

Each case requires the contractor to educate the government "preparing activity" responsible for the MIL-SPEC and MIL-STD. In many cases, the government person responsible for the specification or standard has come on board since it was written and does not know or have access to the corporate knowledge that originally developed the requirements. The single greatest problem is one of age. Most specifications and standards are over five years old with the average age of specifications and standards imposed on TI being nine years.

A related area is the imposition of detailed "how-to" instructions in specifications, standards, and drawings. These instructions are confusing and have conflicting requirements. They prevent TI from using the best, most cost effective process or method to accomplish the task. More freedom to produce a quality end item which meets performance and functional requirements would result in significant cost savings and quality improvements.

Some specific examples of MIL-STD/MIL-SPEC problems discussed are:

* MIL-C-5541C: Excessive test requirements to verify aluminum corrosion resistance.
* QQ-P-35B: Over specification on details of acid concentrations, rinse water temperature, and immersion times.
* MIL-STD-454 Req. 67/MIL-STD-130: Detailed requirements prevent the use of newer, more durable marking technologies.
* No MIL-STD/MIL-SPEC addresses the new and desirable technology of powder coatings.

TI made the following recommendations:

* Provisions of existing streamlining policy and directives should be more aggressively implemented, particularly the restrictions on unlimited specification tiering.
* Greater use should be made of existing commercial and industry standards when applicable.
* Requirements should be specified in terms of functional performance rather than specific manufacturing processes.
* The use of a contract clause stating "any specification or standard that is over five years old is for guidance only" should be considered.

APPENDIX A

TABLE OF ACRONYMS

Acronym	Definition
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AMRF	Automated Manufacturing Research Facility
ANSI	American National Standard Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society of Nondestructive Testing
BMP	Best Manufacturing Practices
CAD/CAM	Computer-aided Design/Computer-aided Manufacturing
CIM	Computer Integrated Manufacturing
CMM	Coordinate Measuring Machines
CNC	Computer Numeric Control
CPU	Central Processing Unit
DOD	Department of Defense
DOE	Department of Energy
DSEG	Defense Systems and Electronics Group
ECN	Engineering Change Notices
EMPF	Electronics Manufacturing Productivity Facility
ET	Effectiveness Team
ETSC	Expendable Tooling Standardization and Control
FMS	Flexible Manufacturing System
GD&T	Geometric Dimensioning and Tolerancing
HARM	High-Speed Anti-Radiation Missile
HASS	Holder/Adapter Selection System
INPACS	Integrated Numerically Controlled Processing and Control System
JIT	Just-in-Time

Acronym	Definition
LAN	Local Area Network
LED	Light Emitting Diode
M&T	Methods and Tooling
MCTI	Metal Cutting Tool Institute
ME	Mechanical Engineering
MIL-SPEC	Military Specification
MIL-STD	Military Standard
MIR	Method Improvement Report
MTI	Metalworking Technology, Inc.
NC	Numerically Controlled
NIST	National Institute of Standards and Technology
NDI	Nondestructive Inspection
PC	Personal Computer
QC	Quality Control
SAF	Speeds and Feeds
SIPS	Semi-intelligent Process Selector
SQC	Statistical Quality Control
TI	Texas Instruments
TOW	Thermal Optical Weapon
TQC	Total Quality Control
TRICS	Terminal for Remote Interface and Control System
WIP	Work-in-Process

APPENDIX B

BMP REVIEW TEAM

Team Member	Agency	Role
Leo Plonsky (215) 897-6686	Naval Industrial Resources Support Activity Philadelphia, PA	Team Chairman
	Lemmon Avenue (Dallas) Team	
CDR Richard Purcell (202) 692-3422	Office of the Assistant Secretary of the Navy (S&L) (RM&QA-PI) Washington, DC	Team Leader
James Williams (619) 939-2951	Naval Weapons Center China Lake, CA	
William Rippey (301) 975-3417	National Institute of Standards and Technology Gaithersburg, MD	
William McAninch (202) 692-0815	Office of the Assistant Secretary of the Navy (S&L) (SPECAG) Washington, DC	
Joseph Szoo (505) 667-8724	Los Alamos National Laboratory Los Alamos, NM	
	Sherman and Trinity Mills Team	
Robert Jenkins (301) 227-1363	David Taylor Research Center Bethesda, MD	Team Leader
Jack Tamargo (707) 646-2137	Mare Island Naval Shipyard Vallejo, CA	
Wayne Koegel (202) 692-6025	Naval Air Systems Command Washington, DC	
Richard Celin (201) 323-2173	Naval Air Engineering Center Lakehurst, NJ	
Alice Giampapa (609) 939-0020	TRIAD Engineering Co., Inc. Runnemede, NJ	Administrative Support

APPENDIX C

PREVIOUSLY COMPLETED SURVEYS

BMP Surveys have been conducted at the companies listed below. Copies of survey reports for any of these companies may be obtained by contacting:

Office of the Assistant Secretary
of the Navy (Shipbuilding and Logistics)
Production Assessment Division
Attn: Mr. Ernie Renner
Director, Best Manufacturing Practices
Washington, DC 20360-5100
Telephone (202) 692-0121

COMPANIES SURVEYED

Litton Systems, Inc Guidance & Control Systems Division Woodland Hills, CA	POC: Herb Abrams VP Product Support & Assurance (818) 715-3080
Honeywell Inc Underseas Systems Division Hopkins, MN	POC: C.B. Christensen Staff Engineer (612) 931-5648
Texas Instruments Defense Systems & Electronics Group Lewisville, TX	POC: Gary Koster MGR, Manufacturing Support (214) 462-2907
General Dynamics Pomona Division Pomona, CA	POC: Chuck Seeger DIV. VP, Quality Assurance (714) 868-3870
Harris Corporation Government Support Systems Division Syosset, NY	POC: Stan Davis VP Manufacturing (516) 677-3500
IBM Corporation Federal Systems Division Owego, NY	POC: Chuck Yungkurth Senior Engineer Mfg Systems (607) 751-2261
Control Data Corporation Government Systems Group Minneapolis, MN	POC: Terry Krinke Mgr, Mfg. Tech. & Plng. (612) 853-4190
Hughes Aircraft Company Radar Systems Group Los Angeles, CA	POC: Tom Kelley Director, Quality (213) 615-7102

ITT Avionics Division Clifton, NJ	POC: Ed Stuczynski VP/Director, Manufacturing (201) 284-4392
Rockwell International Corp. Collins Defense Communications Cedar Rapids, IA	POC: Jim Bronson DIR, Advanced MFG Systems (319) 395-2160
UNISYS Computer Systems Division St Paul, MN	POC: Howard Seim CCAPS Program Manager (612) 456-6254
Motorola Government Electronics Group Scottsdale, AZ	POC: Ray Currens Section Manager (602) 949-3668
General Dynamics Fort Worth Division Fort Worth, TX	POC: Harry Englert Advanced Program Planning (817) 777-8537